Abstract

Fatigue in concrete is a complex phenomenon involving formation of microcracks, their coalescence into major crack and simultaneous formation of the fracture process zone ahead of the crack tip. The complexity is further enhanced because of the interaction among cracks at micro, meso and macro levels. Complex phenomena are best dealt through an energy approach and hence it is reasonable to use the theory of thermodynamics. Also, since fatigue is an irreversible process, the theory of irreversible thermodynamics provides the appropriate framework to develop models to describe this phenomenon.

Fracture mechanics and damage mechanics are two theories that are based on physically sound principles and are used to describe failure processes in materials. The former deals with the study of macroscopic cracks, whereas the latter defines the state of microcracking. In this study, the concepts from these theories are utilized to improve understanding and modeling of the process of fatigue in concrete.

Concrete exhibits size effect and therefore it is important to identify parameters that are size independent and can serve as failure criterion under fatigue. In the present study, the thermodynamic function entropy is identified for this purpose and examined for its size independency and its use as a material property to characterize failure of concrete under fatigue. The amplitude of fatigue loading is in general, much below the monotonic peak load and this results in a progressive and gradual damage of the material. This damage occurring at micro level is reflected in the macro properties, such as stiffness. Hence, in this study, stiffness degradation is related to fatigue damage.

In the thermodynamic formalism, dissipative phenomena are described by a dissipation potential or its dual, from which evolution laws for internal variables could be defined. No analytical expressions for dissipation potential or its dual are available in the literature for fatigue of concrete. In the present study, closed form expressions for dual of dissipation potential are derived using concepts of dimensional analysis and self-similarity in fracture mechanics and damage mechanics theories. Consequently, a fatigue crack propagation law and a fatigue damage evolution law are proposed respectively.

Additionally, since at a given time, a structural member may undergo both macro and microcracking, a method is proposed in this study to correlate fracture mechanics and damage mechanics theories by equating the potentials obtained in each theory. Through this equivalence, a crack could be transformed into an equivalent damage zone and vice versa. Also, damage state corresponding to a given crack in a member can be quantified in terms of a damage index.

Conventionally in fatigue studies, the stress-life ($S - N$) curves are used for design purposes. For concrete, these curves are dependent on a number of parameters including size. An analytical way of computing size independent $S-N$ curves is proposed, using a nonlocal damage theory by including aggregate size and specimen size in the formulation. It is realized from this study that fracture mechanics and damage mechanics theories should be used in a unified manner in order to accurately model the process of fatigue in concrete.

Furthermore, based on the models developed in this study, several damage indicators for fatigue of concrete are proposed. The advantages and limitations of each of these indices are presented such that, based on available parameters at hand, the relevant damage index could be used. Additionally, deterministic sensitivity studies are carried out to determine the most important parameters influencing fatigue life of a concrete member.